# An Investigation of Microphysics and Sub-grid Scale Variability in Warm Rain Clouds using The A-Train Observations and A Multi-Scale Modeling Framework

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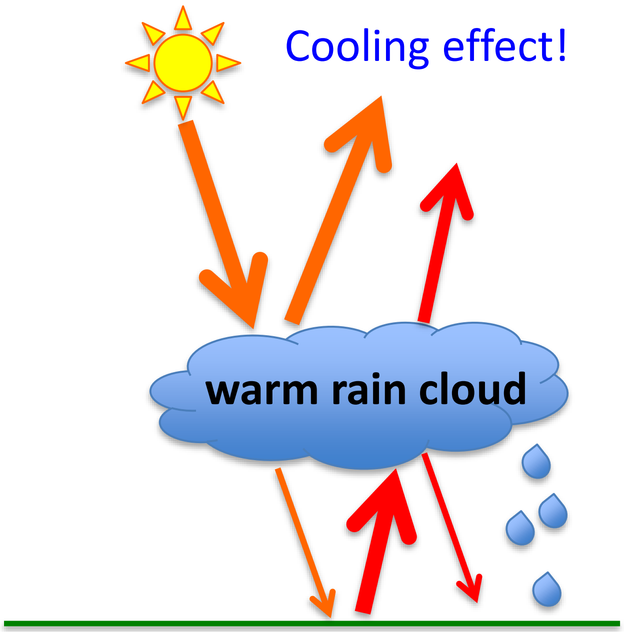
# Introduction: Why are warm rain clouds important?

- The cloud-drizzle-rain processes in warm clouds play a key role in controlling the **hydrologic cycles and energy budgets.**
  - Warm rain clouds are responsible for ~30% of the total rainfall in the Tropics.
  - Warm rain clouds **strongly reflect solar radiation** back to space.
- **Climate projections are very sensitive to the warm-rain formation process.**



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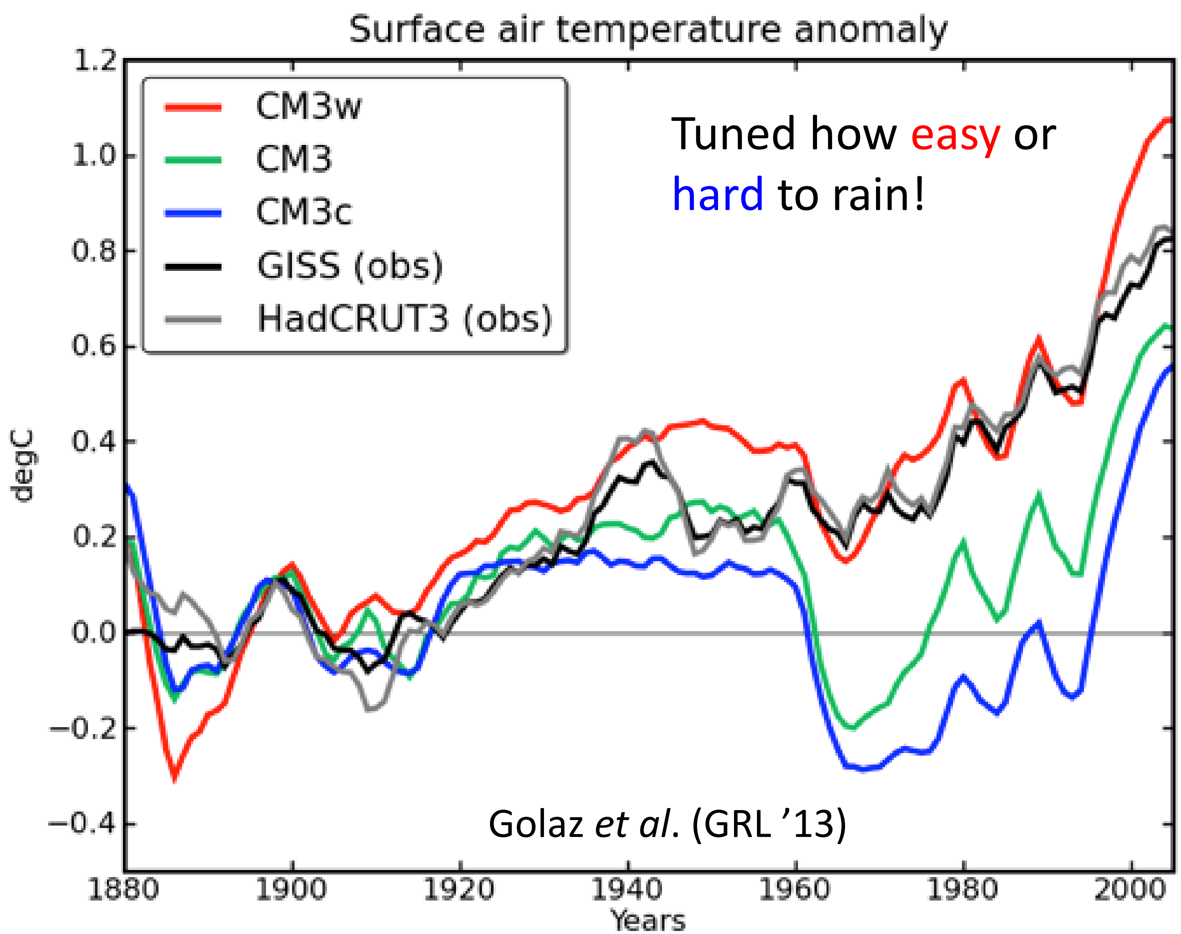


Rain occurs when r=6.0μm
➔ Best temperature trend.

Rain occurs when r=10.6μm
➔ Threshold particle radius is close to observation.

- Prioritize producing realistic global mean climate projections over realistic microphysical processes by using smaller threshold particle radius.
- Rain at a faster rate than is observed, and thus produce too much light rain such as drizzle.

# Introduction: Why are warm rain clouds important?

## Dreary state of precipitation in global models

Graeme L. Stephens,[1] Tristan L'Ecuyer,[1] Richard Forbes,[2] Andrew Gettlemen,[3] Jean-Christophe Golaz,[4] Alejandro Bodas-Salcedo,[5] Kentaroh Suzuki,[1] Philip Gabriel,[1] and John Haynes[6]

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[1] New, definitive measures of precipitation frequency provided by CloudSat are used to assess the realism of global model precipitation. The character of liquid precipitation (defined as a combination of accumulation, frequency, and intensity) over the global oceans is significantly different from the character of liquid precipitation produced by global weather and climate models. Five different models are used in this comparison representing state-of-the-art weather prediction models, state-of-the-art climate models, and the emerging high-resolution global cloud "resolving" models. The differences between observed and modeled precipitation are larger than can be explained by observational retrieval errors or by the inherent sampling differences between observations and models. We show that the time integrated accumulations of precipitation produced by models closely match observations when globally composited. However, these models produce precipitation approximately twice as often as that observed and make rainfall far too lightly. This finding reinforces similar findings from other studies based on surface accumulated rainfall measurements. The implications of this dreary state of model depiction of the real world are discussed.

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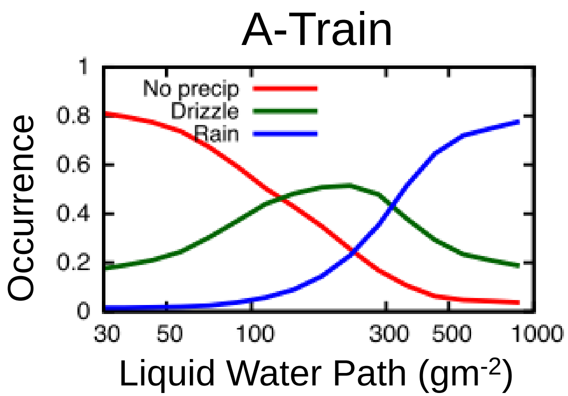
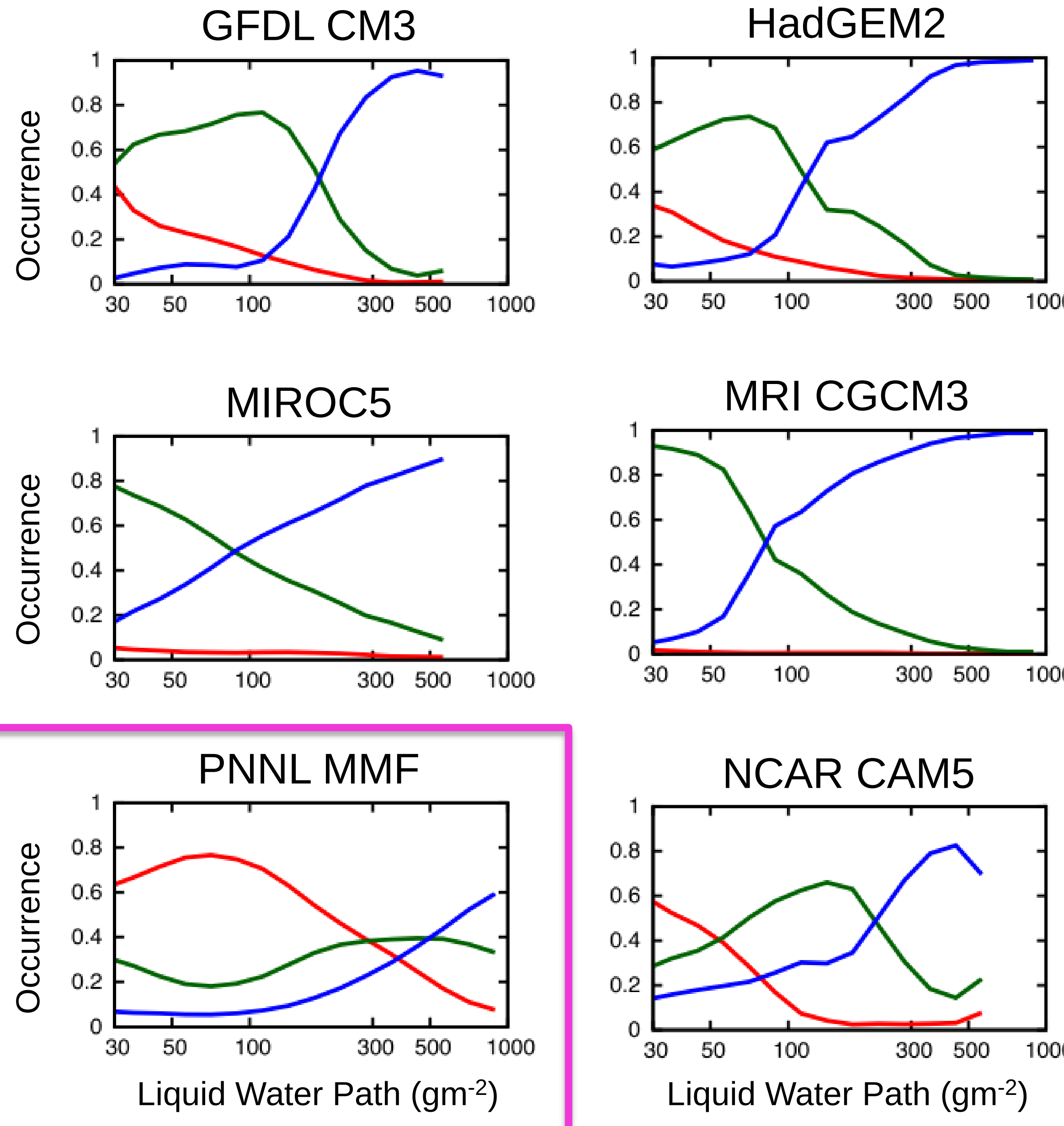
Models make too much light precipitation!


- Detailed observations of microphysical processes in real clouds is needed to improve models.

# Motivation:



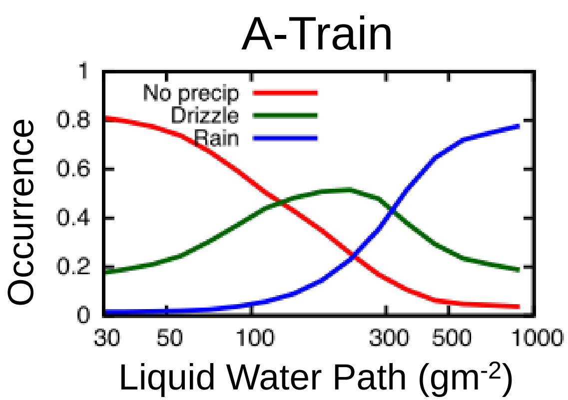

- Auto-conversion process: Khairoutdinov and Kogan.

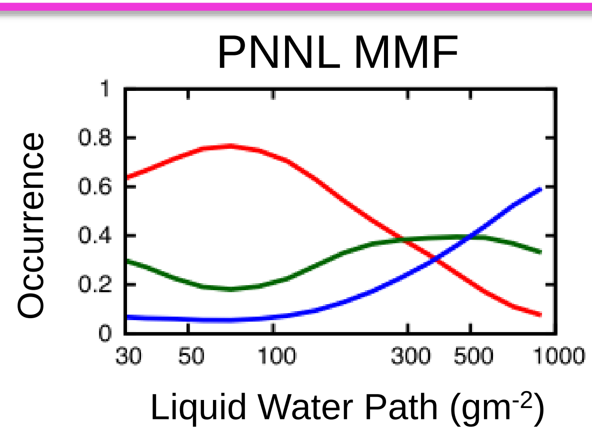
- MMF simulates the most realistic warm-rain formation process.

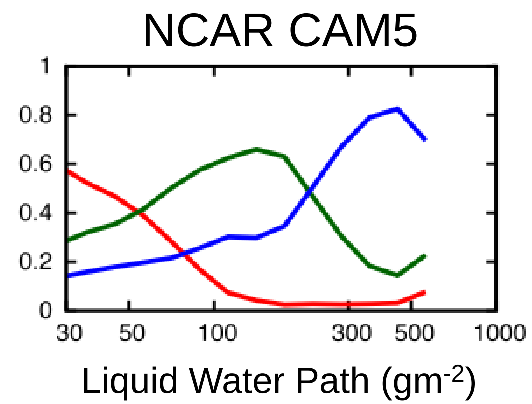
*Suzuki et al., 2015, JAS*

# Motivation:

- MMF has **higher occurrences of cloud mode and lower occurrences of precipitating mode** than observations.
- The rain formation in PNNL-MMF is **less efficient** than real world and other models.
- It is interesting because generally models' rain efficiencies are too high!

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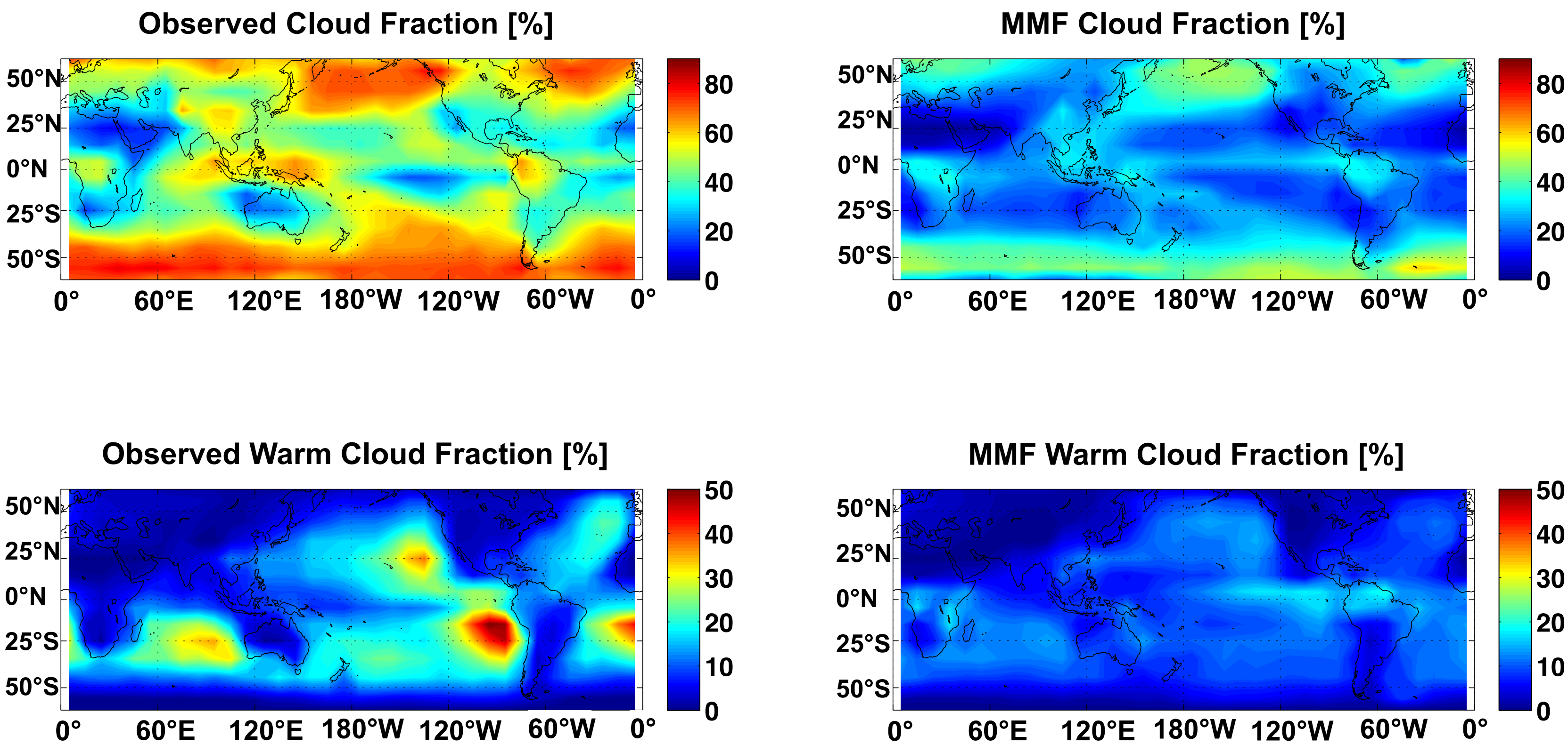
# Objective: Diagnose the possible sources of model biases in PNN-MMF

- PNN-MMF an extension of a multi-scale modeling framework, which has **an embedded 2D cloud-resolving model (CRM)** as parameterizations in each grid column of a general circulation model (GCM).
  - Resolution: 4-km CRM, 1.9x2.5 GCM
  - Time: 20s CRM time step, 10min GCM time step
  - Rain scheme: **Prognostic**
  - Cloud scheme: Two-moment Marrison microphysics in the CRM model
  - Radiative transfer scheme: Rapid Radiative Transfer Model (RRTM)
  - Autoconversion scheme: Khairoutdinov and Kogan (2000)

- We evaluate cloud properties, subgrid variability, and microphysics in PNNL-MMF using A-Train satellite observations (CloudSat+MODIS) to identify the major sources of model biases in PNNL-MMF.
  - CloudSat has a horizontal resolution of 1.7 km along-track by 1.4 km across-track with a horizontal sampling interval of about 1.1 km, and has a vertical resolution of 480 m.
  - **Averaged three consecutive observation pixels together (~3.9km) to come up with observations at the 4km PNNL-MMF spatial scale.**

# Observations vs. PNNL-MMF: Cloud Fraction




- MMF captures the general patterns of cloud distribution.
- The amount of cloud coverage in MMF is much lower than the observations.

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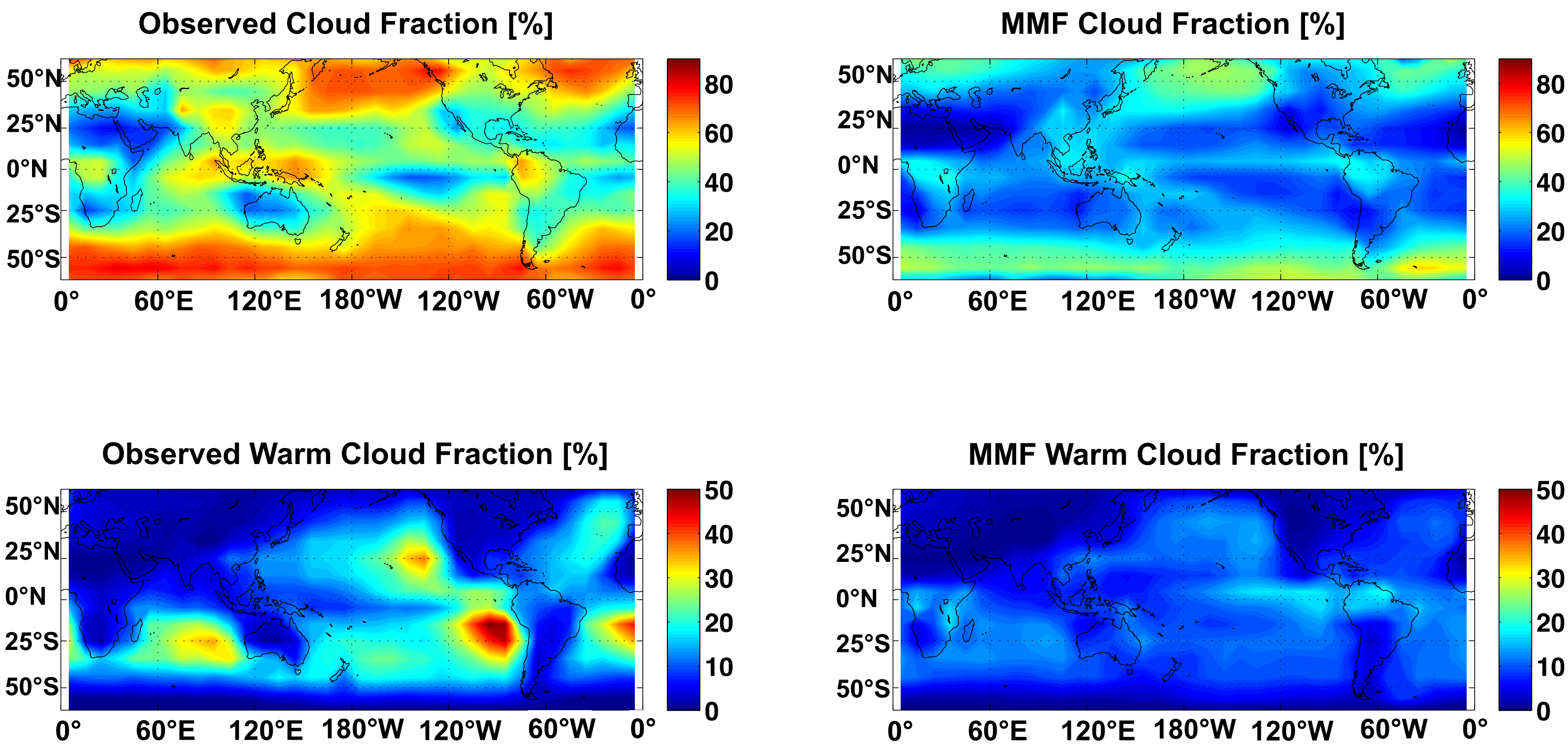
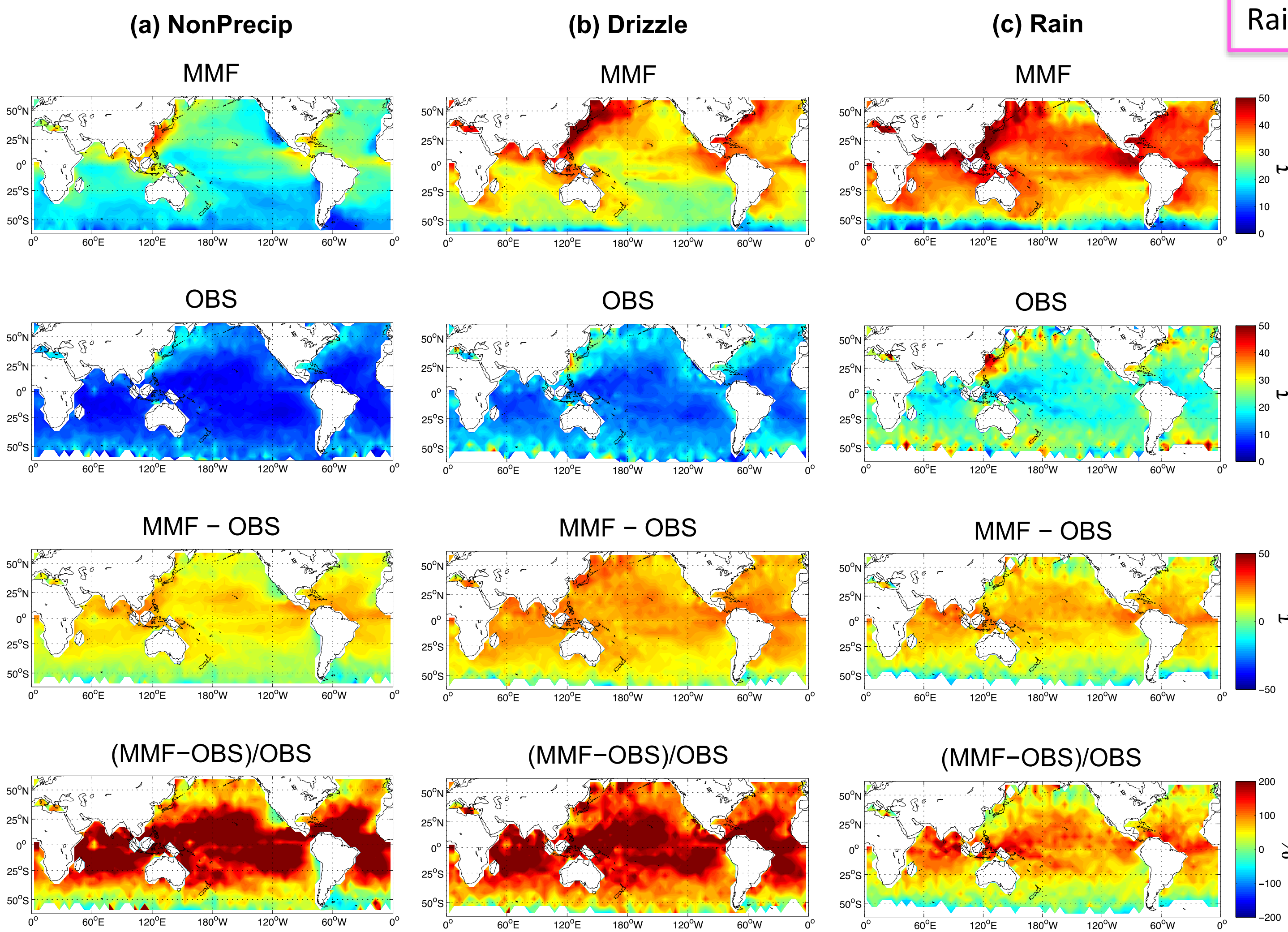



- MMF captures the general patterns of cloud distribution.
- The amount of cloud coverage in MMF is much lower than the observations.

Warm clouds in MMF **must be thicker and/or warmer** than observed clouds to enhance the net cooling effect to maintain the TOA radiative fluxes.

# Observations vs. PNNL-MMF: Optical Depth (τ)

NonPrecip: $Z_{max}$<-15dBZ
Drizzle: -15dBZ<$Z_{max}$<0dBZ
Rain: $Z_{max}$>0dBZ




🡐absolute different

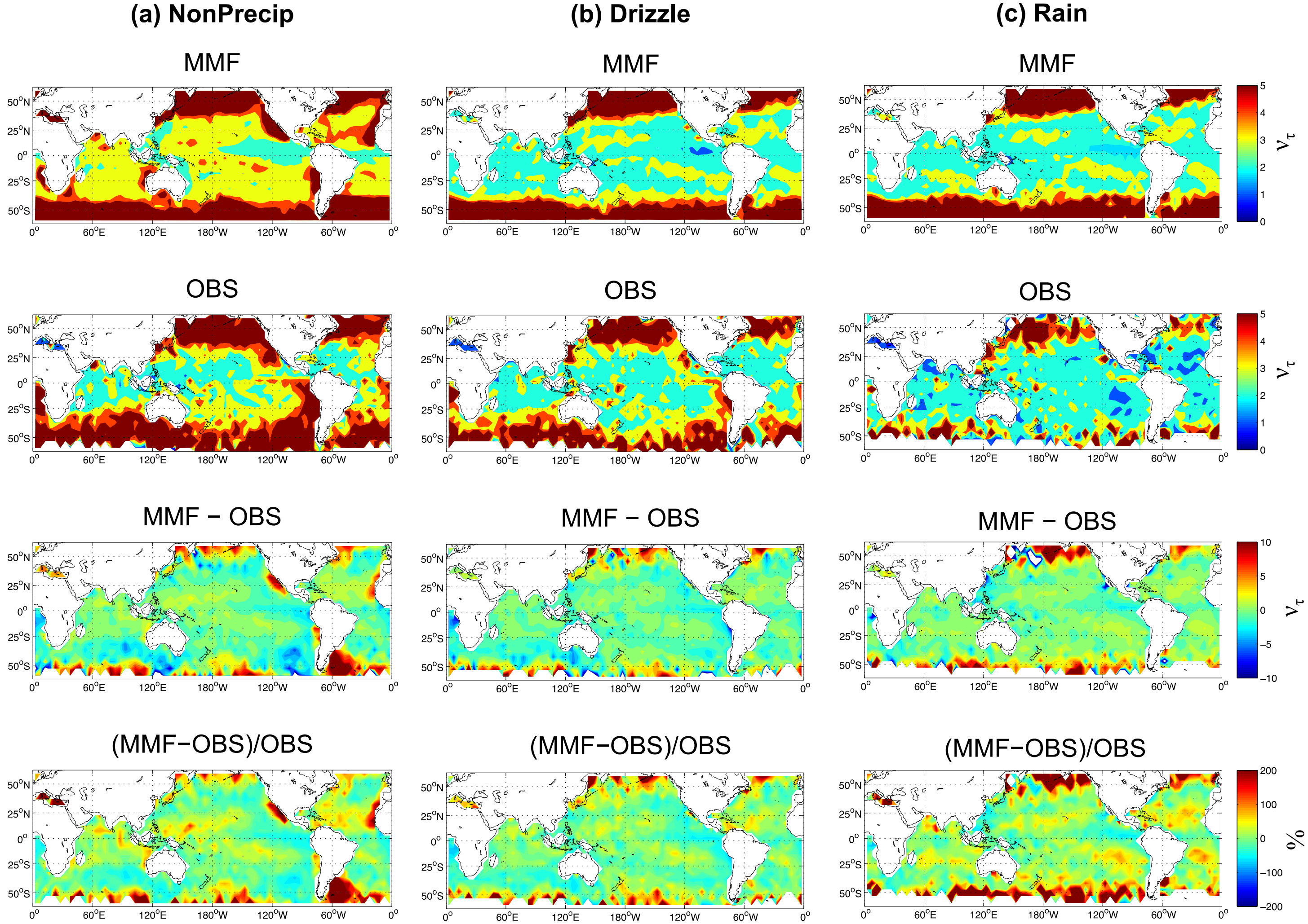
🡐fractional different

- Smaller τ in the cloud mode and higher τ in the rain mode.
- MMF has much higher τ than observations in all modes.

# Observations vs. PNNL-MMF: Optical Depth (τ)

Subgrid variability of τ:

$$n_t = \frac{\bar{t}^2}{s^2}$$

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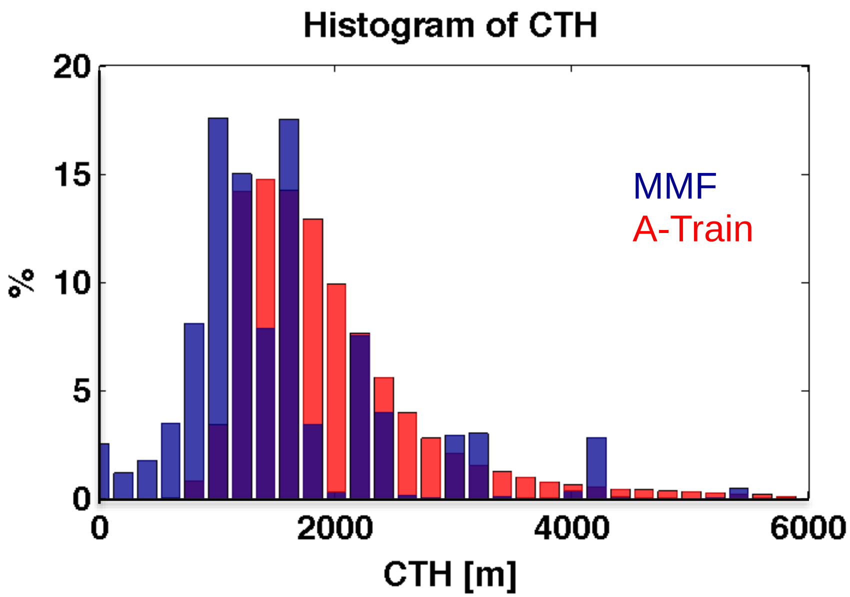
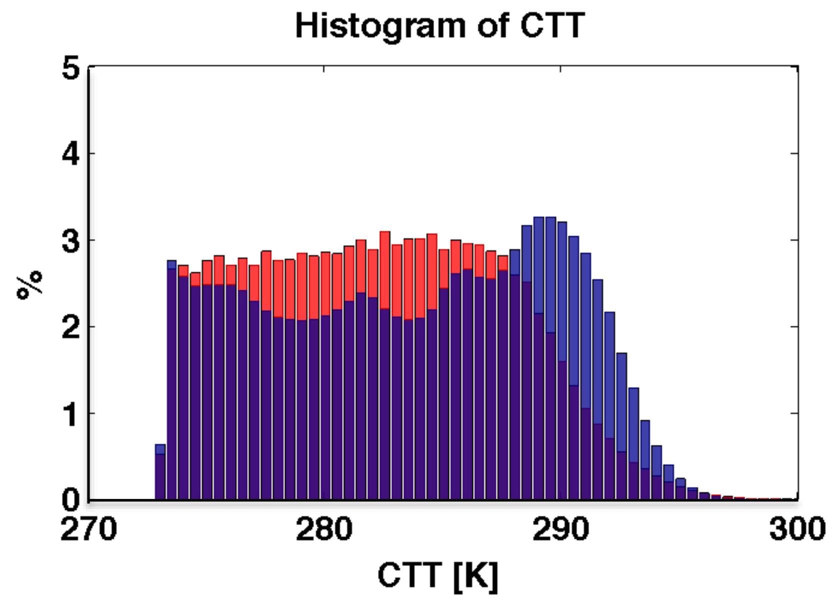
- Higher $\nu_\tau$ in the cloud mode and smaller $\nu_\tau$ in the rain mode.
- The amplitude of $\nu_\tau$ agrees well between observations and MMF.
- Model biases are likely due to its microphysics or dynamics.

# Observations vs. PNNL-MMF: Cloud Top Height and Cloud Top Temperature

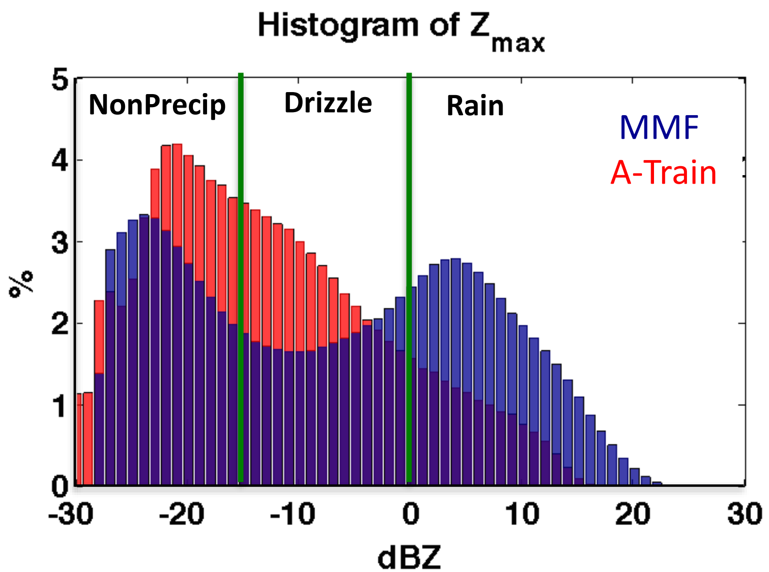



- Simulated warm clouds have lower and warmer cloud top than observed warm clouds.

Simulated warm clouds are optically thicker and warmer than observed warm clouds, which would result in enhanced radiative cooling to space by the simulated clouds and helping compensate for the less cloud fraction to maintain the correct radiative balance.

# Observations vs. PNNL-MMF: How about precipitation?




- The observations show the bell-shaped distribution, while PNNL-MMF shows a bimodal distribution.
- Simulated warm clouds have $Z_{max}$>15dBZ, which indicates either very large precipitation water contents and/or drop sizes.

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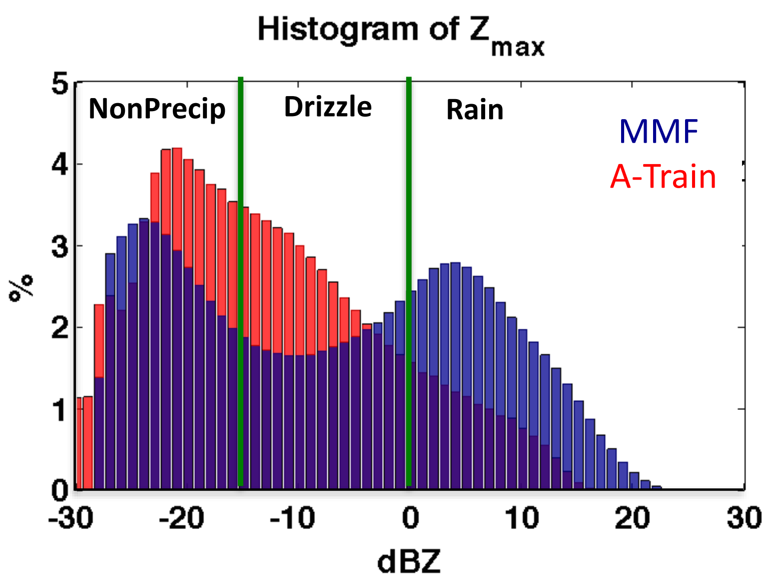


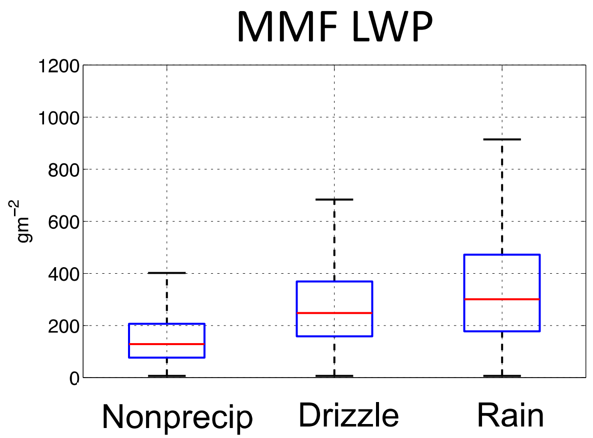


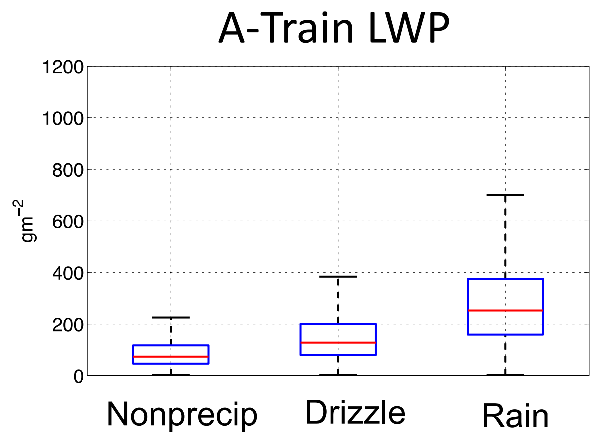


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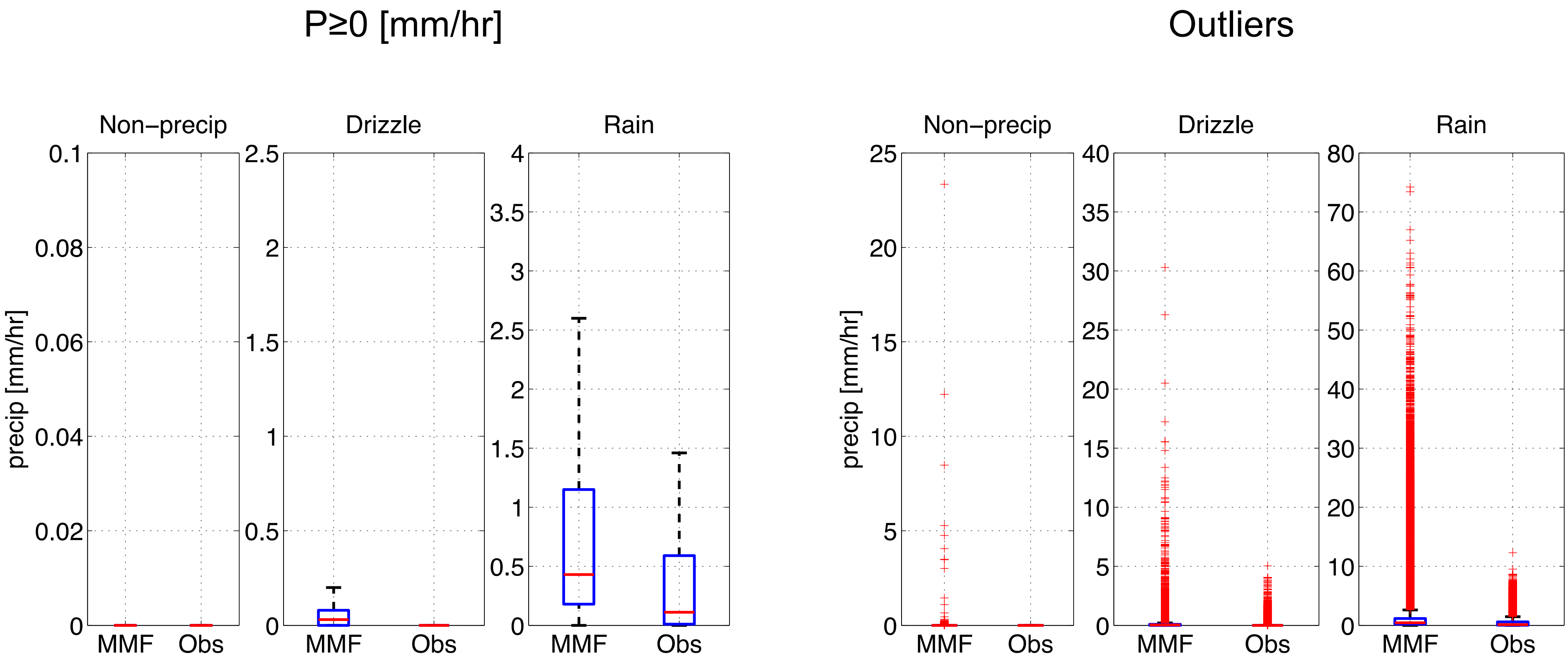
*Clouds in MMF are so "juicy"!!*

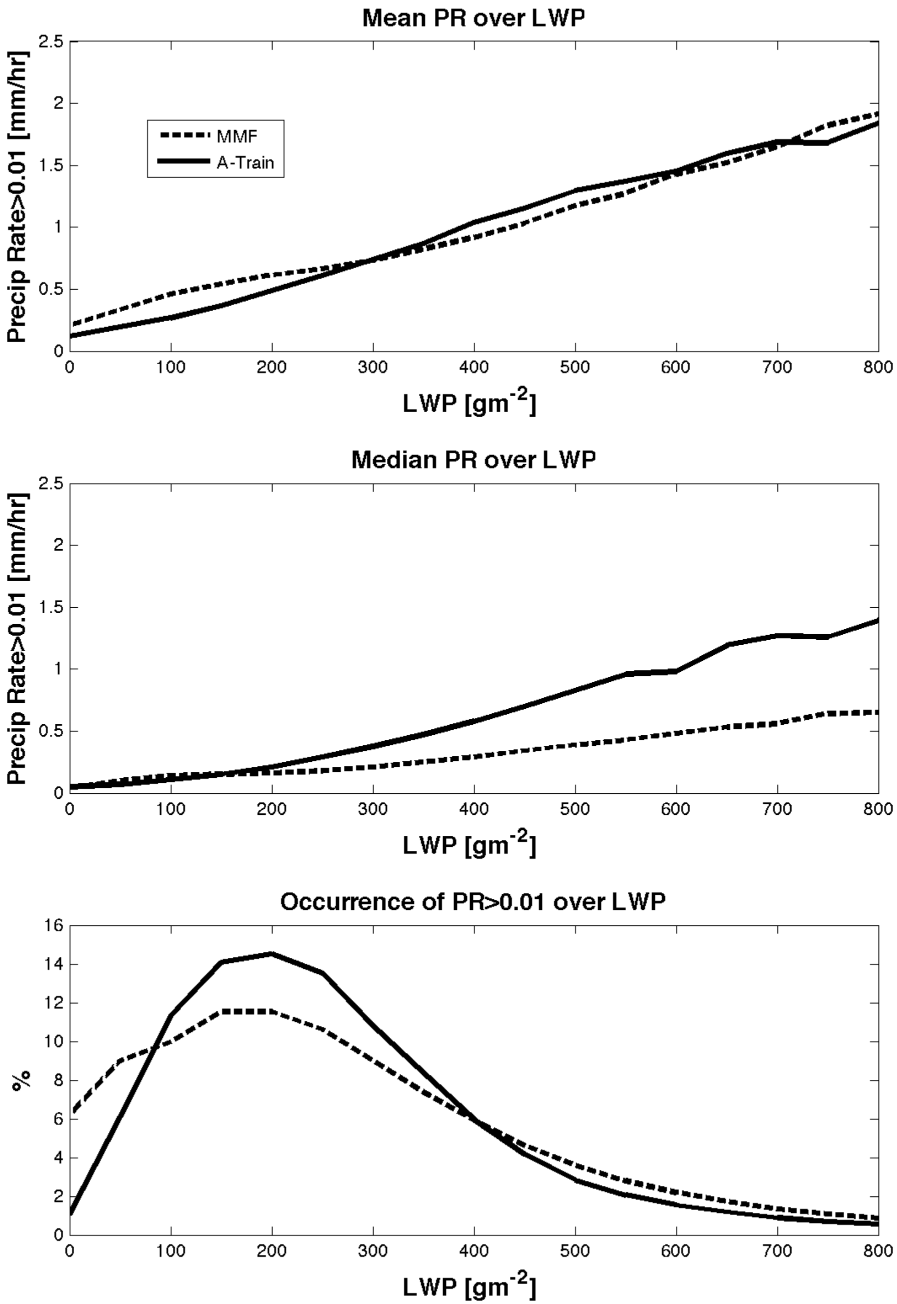
# Observations vs. PNNL-MMF: Intensity of Precipitation




- Although observed and simulated rain intensities are comparable, the range of intensity including outliers is very different between the observations and PNNL-MMF.

These results indicate that the PNNL-MMF produces about the correct mean rain rate to satisfy atmospheric energy balance with an incorrect distribution of rates.

# Observations vs. PNNL-MMF: The Efficiency of the Precipitation Process




- The median precipitation intensity is less sensitive to LWP in PNNL-MMF compare to the observations.
- Rain efficiency is lower in PNNL-MMF than the observations in terms of the median, but LWP is generally much higher in PNNL-MMF than the observations.

There is a compensating error between the cloud water content and the low efficiency of precipitation in PNNL-MMF, which results in approximately the correct mean rainfall rate.

# Conclusions:

- Warm clouds in PNNL-MMF are found to be **optically thicker and warmer** than the observations **to compensate for the smaller net cooling effect** due to smaller warm cloud coverage.

- Sub-grid scale variability of optical depth is realistically simulated, which suggests that the **biases observed in simulated clouds result from a combination of microphysical and dynamical errors**, rather than sub-grid scale representation errors.

- Error compensation between the larger cloud water content and the lower efficiency of precipitation in PNNL-MMF is found, which leads the model to have approximately the **correct mean rainfall rate with an incorrect distribution of rates**.

- It appears that there is a tendency for the PNNL-MMF to produce heavier precipitation (when it occurs) than the observations possibly because **the coalescence process becomes overly efficient as the cloud water content reaches unrealistically high values.**

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